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Travel Time of Public Transport Vehicles Estimation

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Abstract

Effective prediction of speed is central to advanced traveler information and transportation management systems. The speed of public transport vehicles is affected by many external factors including traffic volume, organization and infrastructure. The literature presents methods for estimating travel time on sections of a transport network and vehicle arrival at stops, often making use of the AVL (automatic vehicle location). The aim of the authors of this paper is to identify these factors, their impact and significance on the average speed of public transport vehicles in selected sections of the transport network. The paper presents the results of field studies involving the measurement of travel time of public transport vehicles in the main streets of the Tri-City Agglomeration (Gdansk, Sopot, Gdynia). The study was carried out within the framework of the project for the construction of the urban traffic control system TRISTAR. Based on the collected data the authors built a model of the relationship between the average speed of public transport vehicles and these external factors. The results will be used to calibrate the macroscopic transport model in the Tri-City Agglomeration.

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Keywords: modelling; public transport; travel time estimation

1. Introduction

Speed is an essential parameter in describing traffic conditions in the transport network. This parameter can be used to estimate the quality of travelling in the area. Moreover, with the development of intelligent transport systems, vehicle speed and vehicle flow play an important role in advanced traffic management systems. The speed, along with other parameters, such as traffic flow, provide information about the current situation in the transport network. This issue also applies to public transport, for which the estimation of travel time, including the speed, is necessary for the dynamic transmission of reliable information to passenger information systems. This allows passengers to be kept informed about the arrival times of particular vehicles, thus enabling them to plan possible alternative itineraries, therefore saving time. Information about the variability of travel time on the various sections of the network is also useful for the transport operator's control.

The problem of having to estimate speed and travel time is also present in traffic modelling. In order to make the most accurate representation of traffic flows, occupancy of private sections of the network, as well as considering the issue more broadly - travel behaviour, the average speed for each type and sub-type of link and mode of transport should be properly estimated. Although the speed of private transport is widely discussed in literature, in the case of public transport fixed travel times are generally assumed due to scheduling.

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When considering methods of estimating the average speed of public transport vehicles the movement of these vehicles must be analyzed, this includes travel time, loss of time due to various causes, and also allowing for the stop service times. Identification and analysis of these factors should enable the formulation of a relationship between them and the average speed of the vehicle. This paper presents the statistical summary of the results of travel time research conducted for Tri-City intelligent traffic control system (TRISTAR) and show the complexity of the estimation problem for traffic modelling.

2. Literature review

The literature describes that in estimating average speed and travel time the dynamic information from the road network is mainly used. Four variable parameters are required for the management of the traffic system, volume N(t), occupancy O(t), speed S(t), and vehicle length L(t). To obtain such information, some tools are needed. For example, the simplest device for detection of vehicles, i.e. induction loops can be used for this purpose. Induction loops allow for gathering information on traffic volume, that combined with the known capacity of the road, which depends on its parameters and the traffic signals program, describe the occupancy of a section in the road network.

There are other, more modern methods of average travelling speed measurement that enable collecting more detailed data. The most popular measure is using GPS. The effect of the method can be seen in several web portals which on the map illustrate present (for example, updated every 10 minutes) and historical speed on each section of the transport network. A detailed description of estimating the average travel time with this method has been described in several scientific publications - for example (Li Siyu & Enam & Abou-Zeid & Ben-Akiva, 2013),(Sanaullah & Quddus & Enoch, 2013),(Miyata & Muroaka & Akiyama & Abe, 1997).

Also for public transport the literature describes methods of travel time estimation using advanced passenger information systems (ATIS) and automatic vehicle location (AVL) based primarily on GPS technology.

The extent of discussion related to these topics show that the problem of estimating the speed of motorised transport both private and public is very important. It has been customarily proven that these values are also important in the process of trip modeling, where travel time is one of the key parameters affecting the trip distribution, modal split and trip routing.

To estimate the travel time of private transport vehicles we must know the function of resistance of every link using the variables such as traffic volume, capacity and free flow speed. One of the simplest functions is the one formulated by Overgaard, which is a combination of Soltman's and Smock's function:

$$T = T_0 + \left(1 + \alpha \cdot \left(\frac{Q}{C_p}\right)^{\beta}\right) + \gamma \cdot Q, \tag{1}$$

where:
T – travel time,
T_0 – travel time in free flow,
Q – traffic volume,
C – capacity,
α,β – parameters.

The main feature of this type of function is a discontinuity at the point of critical capacity, compared to the previously used functions. The most popular of the functions for estimating link resistance is BPR function (Bureau of Public Roads, 1964), along with all its varieties BPR2, BPR3:

$$T = T_0 + \left(1 + \alpha \cdot \left(\frac{Q}{C_p}\right)^{\beta}\right) + \gamma \cdot Q \tag{2}$$

where:
T – travel time,
T_0 – travel time in free flow,
Q – traffic volume,
Cp – critical capacity,
α,β,γ – parameters.

When estimating the travel time and speed of public transport vehicles constant scheduled travel times are assumed for modelling. Or they are estimated based on the average travel time on the particular type of link, categorised according to the technical class of road (Birr & Zawisza & Budziszewski & Jamroz, 2012). However, this approach is often undermined, and it is recommended, similar to private transport, to use the function defining the journey time taking into account traffic volume and other factors that may be influential. This is particularly important at the stage of modeling of the public transport network, because the travel time of public transport vehicles is especially vulnerable due to changing traffic volume, so modelling based on the scheduled time may adversely affect the quality of the results (Bauer, 2012).

The Polish literature widely describes subjects of speed and travel time of public transport vehicles, especially trams. However, recently, there have been publications devoted to the analysis of the distortions of bus travel times, showing the complexity of the problem (Bauer, 2013). In the publication (Krych, 2009) the author presents the results of the average and maximum speed of the trams between stops depending on the distance between stops, with indication of the differences between the separated and non-separated route from other traffic. Moreover, attention is drawn to the importance of factors such as driver competence, tram line separation and time management by the operator. Pointing out such detailed and difficult to measure factors demonstrates the complexity of the discussed topics.

3. Scope of Measurements

In May 2012, the Foundation for the Civil Engineering Development conducted measurements of speed and occupancy of public transport vehicles for the implementation of the traffic management system TRISTAR on the main streets of the Tri-City transport network. In the area of the Tri-City measurements were carried out on 128 lines on sections of streets that will be covered by the system.

Measuring travel time of public transport vehicles was carried out by observation from inside the public transport vehicles, along with measurements of occupancy. The observer in each vehicle jotted the vehicle identification number, the line number, the travel time between intersections and the time and reason of each stop of the vehicle.

The research was conducted at intervals for the following periods of transport: morning peak (7:00 – 9:00), noon (10:30 – 12:30), afternoon peak (15:00 – 17:00), evening (21:00 – 23:00) on a typical day of the week, i.e. Monday - Thursday.

The measurements consisted of 25% to 100% of the routes on the private lines of public transport in the analyzed time or 100% of the routes when the frequency of the given line is less or equal to 60 minutes.

4. Results of research

4.1. Obtained statistical data

The obtained results enabled a study to identify factors affecting the overall travel time and to find mathematical relationships that could be further used in the field of travel modelling.

To identify the share of the total generated loss of time for public transport vehicles in the analyzed area the collation of the number of stops was set with division to the causes of stops and differentiated according to the mode of transport (Fig. 1).

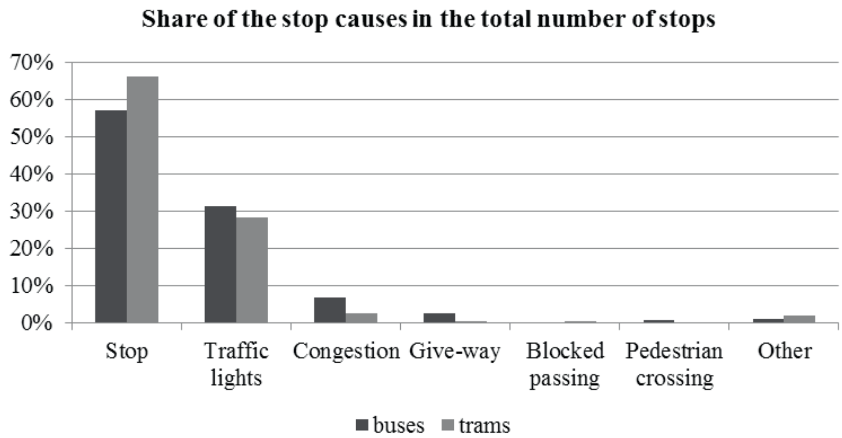

Fig. 1. Share of the stop causes in the total number of stops for trams and buses.

For both buses and trams, the largest share in the total number of stops has been enforced by the service of bus- (or tram-) stops. This shows that disturbance of tram transport is less frequent than bus transport. In Gdansk it is justified by the fact that 85% of the tram lines are separated from vehicular traffic. Other than the service of the stops, the second highest number of stops was reported due to traffic lights. The share of stops at traffic lights, especially for buses, may be related to the characteristics of the analyzed area which included major city streets. For trams an increased share of stops was noted for "other" reasons. Based on interviews with people who were conducting measurements, the authors concluded that the vast majority of observers marked "other" reason for stops when travel was not possible due to other vehicles obstructing the tram lines. It is therefore appropriate to label this reason as "blocked passing". Simultaneously a relatively high share of the reasons for stops (7% excluding the stops at bus stops) was observed, which did not directly result from the infrastructure or the traffic lights, but for random reasons – such as the behaviour of other vehicle drivers who did not observe the road regulations.

The share of total stop times, divided into reasons for stops and vehicle types is a much more valuable statistic than the number of stops (Fig. 2). Analyzing the results, it can be noted that the share of loss of time for buses is greater than the service time of stops. The biggest loss of time is definitely due to traffic lights, which in most cases is also associated with stops because of congestion. This also applies to trams, which confirms a lack of priority for this mode of transport. Separation of tram traffic leads to low loss of time due to congestion.

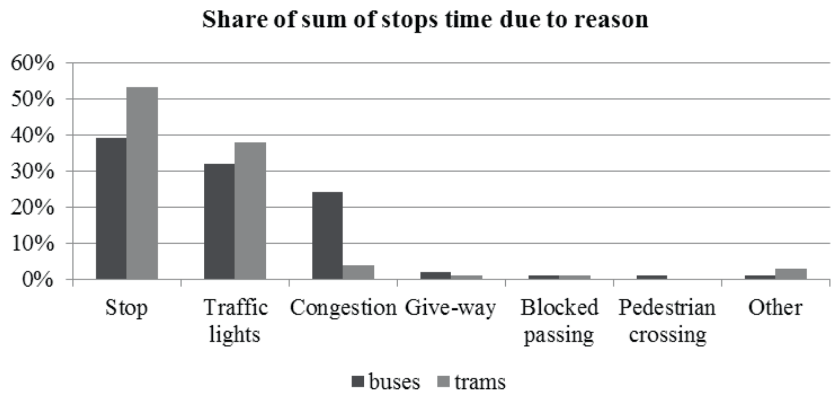

Fig. 2. Share of total stop time reasons.

Another important statistic in traffic condition characteristics in public transport is the average stop time due to reasons for stopping (Fig. 3). The longest average stop time was caused by congestion. Average loss of time at traffic lights was 35 seconds for trams and 27 seconds for buses. Bus stop service time was counted from when the vehicle stopped at the bus stop (in Gdansk vehicles are equipped with so-called "hot button" which passengers use if they wish to enter or exit the vehicle) until the last passenger boards. Service time for tram stops was 21 seconds, and for buses 19 seconds. Such long times may be due to the fact that the area where the research was conducted downtown with the high level of passenger movement. Figures 4a, 4b show the distribution of the stop service time for all vehicles particularly tram stops.

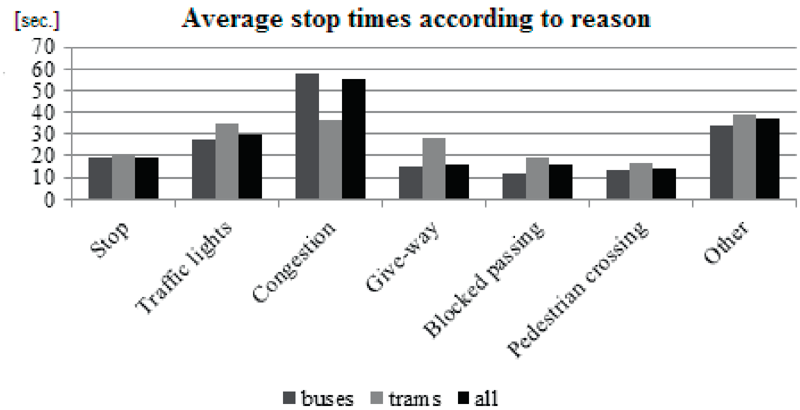

Fig. 3. Average stop times according to reason.

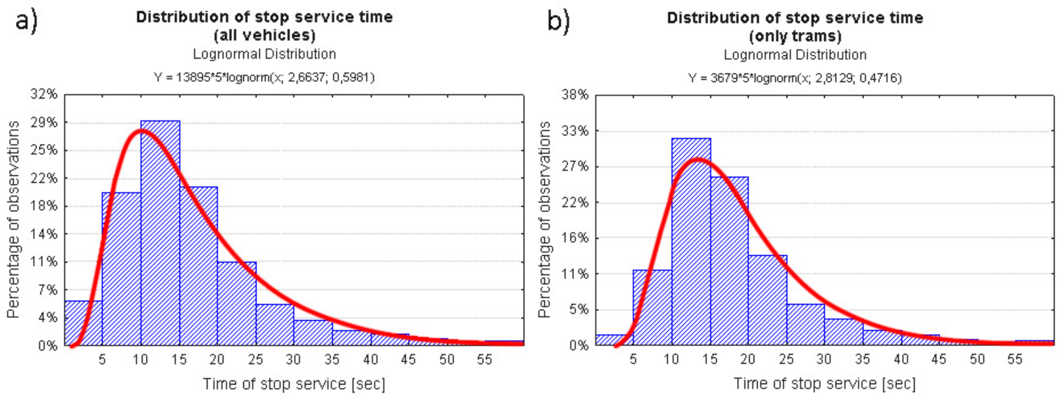

Fig. 4. Distribution of bus stop service time for (a) all vehicles; (b) only trams.

To determine a share of stop times in total travel time, the total stop time on the link between junctions was compared to a total travel time of that link. The average time of all stops on the link was 35% of the total travel time of that link (Fig. 5a), and the share of time needed to service bus or tram stops was 18% (Fig. 5b).

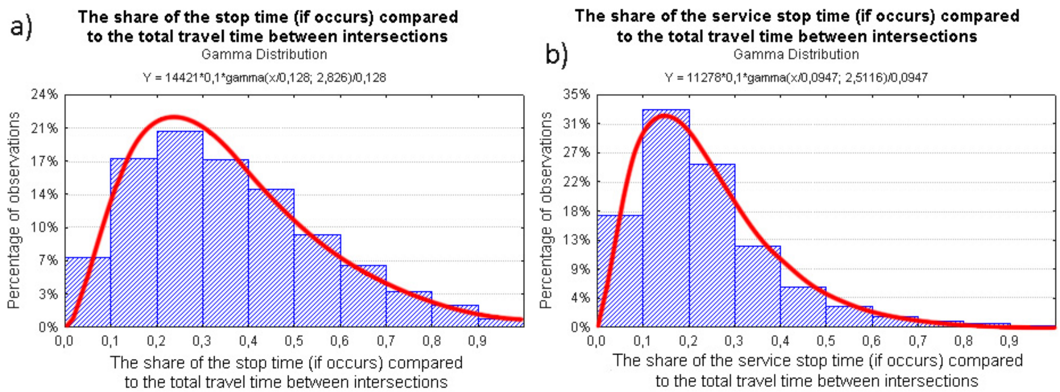

Fig. 5. (a) Distribution of the share of the stop time (if occurs) compared to the total travel time between intersections; (b) Distribution of the share of the service stop time (if occurs) compared to the total travel time between intersections.

4.2. Estimating travel time

The complexity of estimating the speed and travel time of public transport vehicles lays in the attempt to find the relationship between these variables and the distance between intersections, number of bus stops, average bus stop service time and traffic volume. Using the method of regression, a mathematical function was adjusted to empirical data and the correlation coefficient R2 for each number of stops was determined. The results of the obtained relationship are shown in figure 6 (for assumed constant Q/C) and figure 7 (for assumed constant number of stops NS=1). The designated function of travel time dependence on the distance, number of bus stops, average time of bus stop service and traffic volume has a degree of compliance at the level of R2 $\approx$0.61. The function parameters were adjusted to the number of stops, average time of bus stops service, distance between intersections, average traffic volume and average travel time between intersections in each hour (Fig. 6, 7). Finally, the following relationship defining the average travel time between intersections was obtained:

$$T_{av} = 64,7L^{0,5}e^{0,19\mathrm{NS}+0,68\frac{Q}{C}} + 1,21NS \cdot TS_{av} \tag{3}$$

where:

T_{av} – average travel time between intersections (sec.),
L – distance between intersections (km),
NS – number of bus stops,
TS – average bus stop service time (sec.)

Q – traffic volume (veh/h),
C – road capacity (veh/h),

The obtained results and low value of the determination index show that travel time of public transport vehicles is dependent on other factors that are difficult to measure or require detailed identification and categorization (for example road conditions). However, the presented research and analysis confirm that the volume of traffic related to capacity is an important factor in estimating travel time of public transport, similarly to private transport. Moreover this analysis shows, that it is possible to take into account traffic volume in public transport travel time estimation with important parameter value.

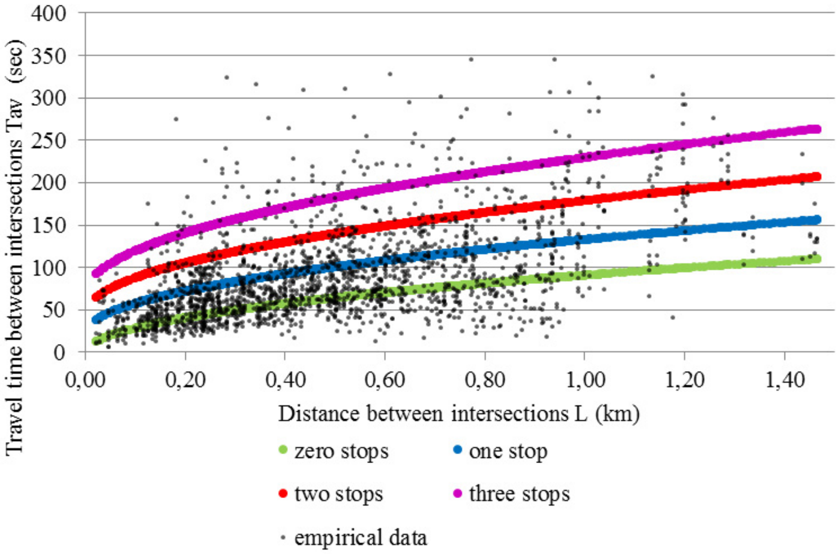

Fig. 6. Estimating average travel time from distance, number of bus stops, average bus stop service time and traffic volume (assumed *TPav* = 19 sec and Q/C = 0,5).

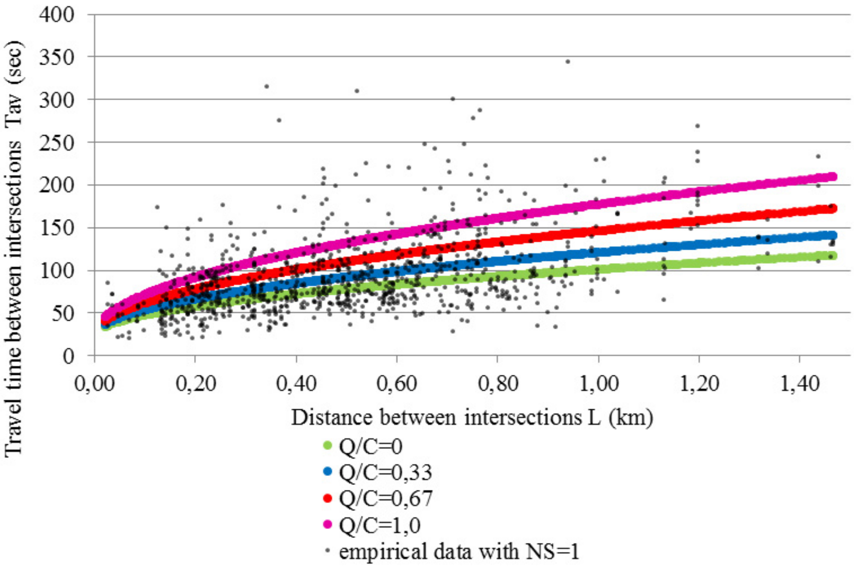

Fig. 7. Estimating average travel time from distance, number of bus stops, average bus stop service time and traffic volume (assumed TP_{av} = 19 sec and NS = 1).

5. Conclusions

Statistics presented in this paper form the basis for further research of public transport movement. In addition, it provides a point of reference for efficiency verification of the TRISTAR traffic control system, built in the Tri-City, which includes implementation of priority for public transport vehicles.

The obtained results show the complexity of estimating the speed and travel time of public transport vehicles for traffic modelling. The number of factors affecting these values is high, and some of them are difficult to measure. In order to obtain a similar relationship as in the private transport link resistance function, the dependence of traffic of public transport vehicles on traffic volume should be analyzed. However, it seems, that in order to build more detailed models for estimating average travel time of public transport vehicles, each section of the network should be thoroughly characterized in terms of both infrastructure (also taking into account the road condition) and traffic organization. Then to aggregate into groups with similar characteristics and build a function that allows for estimations of the average speed or travel time for them. Also, parameters such as average bus stop service time may be determined by using statistical distribution. These problems and issues will be the next object of our research.

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